NBSIR 76-1094 (R)

Standards for Computer Aided Manufacturing

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Office of Developmental Automation and Control Technology
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Interim Report

June, 1976
Issued July, 1976

Prepared for
Manufacturing Technology Division
Air Force Materials Laboratory
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U.S. DEPARTMENT OF COMMERCE, Elliot L. Richardson, ***Secretary***
Edward O. Vetter, *Under Secretary*
Dr. Betsy Ancker-Johnson, *Assistant Secretary for Science and Technology*
NATIONAL BUREAU OF STANDARDS, Ernest Ambler, *Acting Director*

I. INTRODUCTION

This report identifies and evaluates those existing and potential standards which will be useful to the Air Force in the development and implementation of integrated computer aided manufacturing systems. Such systems, when implemented by the Air Force and by Air Force contractors, will increase productivity in discrete part batch manufacturing by several thousand percent.

The work reported here was supported by the Manufacturing Technology Branch of the Air Force Materials Laboratory at Wright-Patterson Air Force Base under MIPR FY14577600369.

The Five Tasks outlined in the Statement of Work for the MIPR are:

i) Identify and provide current standards applicable to computer aided manufacturing.

ii) Analyze current standards.

iii) Assess actual usage of standards throughout industry.

iv) Hypothesize optimal standards for integrated computer aided manufacturing.

v) Assess the relative roles of existing standards organizations and the Air Force in organizing for the development of optimal standards for computer aided manufacturing.

This document is an interim report covering Task 1. The Air Force Statement of Work is included as an Appendix.

To address the first issue, the identification of relevant standards for CAM systems, it is first necessary to consider the use and importance of standards and the nature of CAM systems. From this context one can then evaluate which standards were relevant to the Air Force development and implementation of CAM systems.

II. THE IMPORTANCE OF STANDARDS IN CAM

The applications of computers to the control of machines represents a fundamental revolution in manufacturing technology. This trend, which first started with numerically controlled machine tools, has its logical extension in a totally automatic factory which can run seven days a week without human intervention and can automatically reconfigure itself to produce custom designed products at mass production costs.

Numerically controlled machine tools are now widely used and understood in manufacturing in a stand alone context, even for small shops. There is a new technology emerging in which general purpose NC machine tools are integrated with automated materials handling systems and higher level computers for planning, scheduling and control. Such systems are able to perform machining operations on randomly sequenced parts.

Such systems range from the Sundstrand Omniline and the Kearney and Trecker Flexible Manufacturing System, which are operational at Ingersoll-Rand, Caterpillar and Allis Chalmers, respectively, to the proposed Japanese Methodologies for Unmanned Manufacturing Systems program. The Japanese program will result in a prototype automatic factory for the production of machine tool parts. The predicted increases in productivity in this facility will be 7000 to 8000 percent compared with a conventional facility.

The key to productivity increases in such manufacturing systems is the coupling of the various elements of the manufacturing process into an integrated system with a centralized computer control system and data base structure.

In a larger context, the integration of computer aided design with computer aided manufacturing, that is, systems in which design of the part creates a geometric data base which directly results in control programs for the NC machine tools, and in which computer systems are used in process planning, inventory control, scheduling, and control of production, offer even larger problems of development and integration of many dissimilar parts. There is now no company offering complete systems on the market.

The largest manufacturing industries have created their own internal integrated systems which are specific to their needs and which are generally held as proprietary and not placed on the market. One can go to a machine tool company and buy NC tools, to a computer service company and buy time sharing support for programming those tools, and one can go to many sources and buy special computer programs or computer programming support for special applications. Further, one can buy stand alone graphic systems including integral software programs, but often the problems of putting together an entire CAD/CAM system for all of these components involves so much engineering and software development effort as to make such systems practically and economically viable for only the largest firms.

The key to developing and using integrated computer aided manufacturing systems in a free marketplace, particularly for medium and small firms who cannot afford special software and engineering, will be the use of adequate standards to insure the compatability of modular system components obtained from competitive suppliers.

III. TYPES OF STANDARDS

The oldest standards, and the usual standards that one normally brings to mind, are those for weights and measures, that is, units for length, weight, and volume that are the basis for commerce and trade and for science. These standards originally were based on dimensions of the human body, which produced measures that were reproducible wherever there was a man, such as the cubit or the yard, the fathom, the foot, and digit, and so on. These units in turn produced artifacts such as yardsticks. For example, in the 16th Century a measuring rod was defined as follows:

> "to find the length of a measuring rod the right way and as it is common in craft . . . take 16 men, short men and tall ones as they leave church and let each of them put one shoe after the other and the length thus obtained shall be a just and common measuring rod to survey the land with."

Such standards of weights and measures are now generally based on independently reproducible constants of nature rather than artifacts and are mandatory and controlled by law.

The second class of standards are those set for consumer protection, in the public interest, such as standards involved in building codes, in pollution control, and in the flammability of carpets, draperies, and children's sleepwear.

The third class of standards are voluntary industry standards which are set by consensus agreement among concerned parties. There are now some 20,000 voluntary standards in force which have been created by more than 400 organizations, covering a multitude of products, practices, test procedures, materials, and other characteristics which have been found to be in the interest of those parties involved to reach a common understanding and common practice.

The driving force behind voluntary standards is economic. The first step in this direction occurred at the start of the 19th Century when Eli Whitney produced the first rifles from interchangeable parts which obviated the need for handwork in assembly. Production became simpler and less expensive. Mass production is the logical extension of this concept through an entire industry, and it requires standardization through the entire economy. In fact, it is hard to imagine a time during this century when nuts and bolts wouldn't fit together unless they came from the same manufacturer. Such a situation would obviously bring modern assembly lines grinding to a halt.

De facto standards can be created by common usage or by oligopolistic markets such as exist in the computer field. Such standards are usually internal company standards that are picked up by others using or interfacing to that company's products. An example is the existence of a billion dollar independent computer peripherals industry that produces products that interface with EBCDIC as the code for data interchange, in conflict with the ANSI Standard (ASCII). EBCDIC is thus a de facto standard in the industry.

Finally there are internal company standards that have been set by fiat, planning, or historical accident. Such standards are necessary to the efficient operation of any large organization and can become extremely rigid and formalized. An example, is a part or drawing numbering scheme. However, they are generally unique and are not relevant to the Air Force ICAM program.

Why Voluntary Standards Work

Voluntary standards work because of the economic forces that are involved. Standards can be a powerful management tool to improve efficiency and reduce costs.

In 1920, Herbert Hoover initiated a study of six industries as President of the Federated American Engineering Society. The conclusion was that nearly 50 percent of the cost of production and distribution could be eliminated through standardization and simplification. Fifty percent of the costs of production and distribution is worth the large amount of effort needed to reach voluntary standards in any manufacturing industry.

Standards are not necessarily fixed and inflexible. Obviously, any voluntary system, can only work as long as the parties involved believe the standards are useful. When change is appropriate, change occurs under a voluntary system.

Standards for Computer Aided Manufacturing

Most engineers and computer scientists readily agree that modular design is a good philosophy. Indeed, that is the concept that is most appropriate in CAM. The standards that are most needed for computer aided manufacturing systems are the interface specifications that allow all of the various modular components of manufacturing systems, computer programming, and the computer language and standards that will make the software independent of the specific hardware environment. This concept is particularly important to medium- and small-size firms, those below the top 1000 firms who account for 60 percent of the value of shipments in the discrete parts manufacturing industries.

In many cases the existance of an appropriate interface can actually stimulate technological innovation and market place competition. The development of numerical control and APT offer an excellent example of this concept. When NC tools were first installed in the aerospace industries between 1958 and 1960, it was almost impossible to make tapes that ran tools. Each different system had its own tape sizes, data codes, formats, servo characteristics and programming requirements, and the programs had to be figured out with a hand calculator and punched on a Flexowriter. This state of chaos was brought under control by standards that are now controlled by Electronic Industries Association Committee IE-31 on Numerical Control. Standards were necessary for widespread industry use of NC.

The APT language, which was created in this environment as a computer program to prepare the tapes for all of those dissimilar and incompatible machine tools, was created in a two level structure, where the APT processor produced a CL (cutter location) data file which was then run through a post processor to convert it to specific output format for a given machine tool.

This CL tape or CL file has become as excellent interface standard for computer aided manufacturing systems. For example, the interactive graphics systems now available from several suppliers can produce a CL data file which can be directly run through existing post processors. At this point, from the point of view of information flow in a computer control hierarchy, all of the machine tools are functionally equivalent. In fact, one new CNC system takes CL file as direct input.

This concept of standard interfaces is very powerful and if extended into a total manufacturing system, would allow the possibility of creating a system out of modules bought from competitive manufactures. Alternatively, large aerospace prime contractors could create proprietary application modules to maintain their competitive position without the total cost of overall system design and implementation.

In addition, if the system modules are written in standard languages that are machine independent, then the modules can be transferred to other users and be integrated into a total system without special engineering or software development.

The Air Force has recognized these concepts in the Statement of Work for the NBS support project. The next section will consider the identification of the standards relevant to the Air Force ICAM program.

IV. CAM ARCHITECTURES

To identify where standards are needed in a large system, and particularly to identify where the major system interfaces are located, one must have a concept of the overall system structure or architecture.

Since the Air Force will develop the detailed ICAM architecture after this study is complete, existing system concepts and architectures will be examined to identify the common elements to guide the further presentation and discussion of relevant standards.

In discussing the architecture of CAM it is soon apparent that there is no widely accepted definition or overall concept. CAM can be defined as the application of computers in the manufacturing process. This definition is very global and does not clearly define the boundaries of CAM and does not identify concepts which are not CAM.

Several examples are useful. The early use of computers in manufacturing industry fell into three main categories: business applications such as payroll and accounting programs, scientific and engineering support programs, and APT. In fact, it has been estimated that fully 30 percent of the use of IBM 709 series machines in the aerospace industry in the first half of the 1960's was committed to APT runs. Subsequent uses included inventory control, customer order servicing, scheduling and control, and computer aided design. It should be noted that, with the exception of interactive CAD systems, most CAM programs have been batch type programs, even when available on time sharing systems to smaller companies.

Two typical examples of CAM systems are the Rock Island Arsenal Pilot Automated Shop Loading and Control System (PASLACS) specifications (Figure 1), which cover several commonly available systems and the Norwegian AUTOKON 71 programs for ship building shown in Figure 2. Even if an online data base is kept of all files, these types of systems are basically a set of programs that run in batch mode.

The more recent development of large Data Base Management Systems, Management Information Systems, communication systems, and networks, including many computers and real time operating systems, has led to concepts of CAM systems in which there is a real time interaction with the system. IBM's COPICS, Figure 3, is an excellent example, as is the CAM system in use at McDonnell Douglas, Figure 4. The Caterpillar system, Figure 5, shows the use of such concepts outside of the aerospace industry.

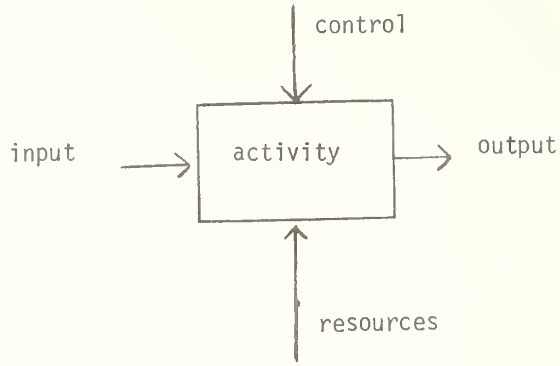
Future systems concepts emphasize distributed processing and data structures and "smart" data base concepts. A "smart" data base is one which can answer questions about information that is implicitly, as well as explicity, in the data through the use of modelling or simulation programs. The ICAM schematic, Figure 6, illustrates this idea.

The development of concepts of integrated manufacturing systems, in which applications programs are all interfaced to a central operating system, data base management system and management information system structure which can operate in a real time multi-user manner, possibly with several computers coupled in a hierarchy or other network, has led to a proliferation of concepts. There are significant commonalities that are often obscured by different formats of presentation and by the use of conventions that mix physical activities with information processing activities.

In fact, there are three different architectures that are simultaneoulsy present in a CAM system and which must all be considered together. These are:

1. <u>THE ARCHITECTURE OF THE MANUFACTURING SYSTEM</u>

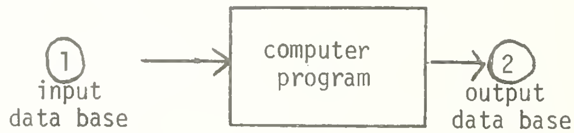
   This is the structure of the operation of the manufacturing process itself, including both physical activities and the management of those activities. Figure 7 shows the CAM-I Advanced Technical Planning Committee concept of a manufacturing system, using the cell model convention:



Note that in a cell model the input and output may be either physical material or information, depending on the activity.

2. THE ARCHITECTURE OF THE CAM SYSTEM

This is a set of computer programs that process information. The input and output are always data which, of course, may have a physical analog in material or operations in the manufacturing process. Figure 8 shows an architecture of a CAM system developed by the CAM-I Standards Committee, working from the CAM-I Long Range Plan, and using a modified "nodes and paths" convention:



This convention was chosen to highlight the data bases which are the interfaces in a CAM system.

3. THE ARCHITECTURE OF THE COMPUTER SYSTEM WHICH RUNS THE CAM PROGRAMS

Figure 9 shows a schematic of part of a computer system with at least two computers networked together. This schematic was developed to show the main elements of a computer system that must be considered in evaluating standards relevant to CAM.

Note that if only one computer is involved and the Input/Output channels are dropped, the parts of the schematic could be "wrapped around" the data base to obtain the form of Figure 6. Figure 9 is thus a valid representation of the ICAM concept, with the communications subsystems explicitly identified.

It is this architecture of a computer system, Figure 9, that will receive the greatest attention in this study, since it is here that systems standards must be set to assure software transportability and computability.

V. STANDARDS RELEVANT TO CAM

There are both formal and de facto or company standards relevant to each of the different architectures discussed above.

Examples of Standards relevant to Manufacturing:

drawing specifications
fastener standards
tooling standards
safety standards
pallet standards
part numbering conventions
quality control standards

Examples of Standards relevant to CAM:

data base formats
NC part programming languages
group technology coding schemes
standard process plans
inventory
programming languages for robots and automatic test equipment
CAD/CAM interface

Examples of Standards relevant to Computer Systems:

communication codes and protocols
documentation standards
programming languages
data base management systems
media standards.

In considering the standards relevant to the Air Force ICAM program, NBS has made the following decisions:

1. No manufacturing standards will be considered. Most of these standards are internal company standards. Hence arbitrary decisions by the Air Force or ICAM contractors will become valid de facto standards. Better yet, every effort should be made to make the ICAM software independent of such detailed data formats so that companies may continue to use internal standards for such things as part numbering. This will maximize the utility of ICAM software. Standards on hardware (tooling, fasteners) will be well known by the designer of new equipment under the ICAM program and can best be selected at the time of implementation. Material will be provided to the Air Force separately on the metric issue.

2. In the CAM area, only NC part programming languages and the interface with design will be considered. There are formal standards in both of these areas. Group technology codes will not be considered since that is the specific subject of study under the ICAM program. Programming languages for robots are not standardized, and ATE and process control languages are oriented to electronic testing and continues process control rather than discrete part batch manufacturing, which includes air frame manufacturers.

   Again, because of lack of formal standards, the Air Force can make decisions that will result in de facto standards but should strive to create a system that will allow each user maximum flexibility in implementation. The CAM-I process planning system (CAPP) is an example of this concept since it allows use of any group technology coding scheme.

3. Standards for computer systems will receive the bulk of the attention of this report. Three key concepts will be pursued in evaluating standards:

   - System integration: data interfaces between CAM application programs
   - Software portability: interfaces between CAM programs and host computer systems
   - Distributed processing capability: interfaces between computers in distributed system

   The second concept is the key to widespread utilization and impact of the Air Force program. The third concept, distributed processing capability, will be important if ICAM is to remain relevant over any length of time. The rapidly dropping costs of mini and microcomputers and the availability of software to create and utilize distributed processing and distributed data structures indicate that the next generations of computer systems will be distributed in nature.

   Within this set of assumptions, then, the standards that are relevant to the Air Force ICAM program, in priority order are:

   A. Communications Standards
   B. Programming Languages
   C. Documentation
   D. Validation and Testing
   E. Media Standards

   In addition, standards and common practices for operating systems and data base management systems will be discussed to identify the technical issues involved system integration.

Lists of special formal standards and de facto standards identified by NBS as relevant to the Air Force ICAM programs, in the context just discussed, are shown in Tables 1 & 2.

Table 1

CAM standards to be considered by NBS:

1. NC Part Programming Languages

   a. ANSI X3.37-1973 APT

   b. Compact II/ ACTION/ SPLIT (New ANSI X3J7 Committee)

2. CAD/ CAM Interface

   a. Institute for Printed Circuits Standard for Printed Circuit Boards

   b. ANSI Y14.26.1 Proposed standard for Digital Representation of Physical Object Shapes

Table 2

Computer System Standards and De Facto Standards

A. Computer Systems Standards - Communications

1. Communication Standards - Hardware

a. EIA RS-232C, Interface Between Data Terminal Equipment and Data Communication Equipment Employing Serial Binary Data Interchange

b. EIA RS-334 (ANSI X3.24-1968), Signal Quality at Interface Between Data Processing Terminal Equipment and Synchronous Data Communication Equipment for Serial Data Transmission

c. EIA RS-408 Interface Between Numerical Control Equipment and Data Terminal Equipment Employing Parallel Binary Data Interchange

d. IEEE Std. 488-1975, IEEE Standard Digital Interface for Programmable Instrumentation, April 4, 1975 (Used in Hewlett-Packard instruments)

e. IEEE Std. 583-1975, IEEE Standard Modular Instrumentation and Digital Interface System (CAMAC: Computer Automated Measurement and Control), November 28, 1975

f. ANSI X3.1-1969, Synchronous Signalling Rates for Data Transmission

g. FIPS PUB 22, Synchronous Signalling Rates Between Data Terminal Equipment and Data Communication Equipment (adopts ANSI X3.1-1969 with two exceptions), February 15, 1973

h. ANSI X3.15-1966 (FIPS PUB 16, October 1, 1971), Bit Sequencing of ASCII in Serial-by-Bit Data Transmission

i. ANSI X3.16-1966 (FIPS PUB 17, October 1, 1971), Character Structure and Character Parity Sense for Serial-by-Bit Data Communication in ASCII.

j. ANSI X3.25-1968 (FIPS PUB 18, October 1, 1971), Character Structure and Character Parity Sense for Parallel-by-Bit Data Communication in ASCII

l. ANSI X3.36-1975 (FIPS PUB 37, GSA Federal Standard 1001, June 15, 1975), Synchronous High Speed Data Signalling Rates Between Data Terminal Equipment and Data Communication Equipment

m. EIA RS-422, Electrical Characteristics of Balanced Voltage Digital Interface Circuits

n. EIA RS-423, Electrical Characteristics of Unbalanced Voltage Digital Interface Circuits

o. EIA SP-1194, Functional and Mechanical Interface Between Data Terminal Equipment and Data Communication Equipment Employing Serial Binary Data Interchange (with RS-422 and RS-423 will replace RS-232-C)

p. CCITT V.28, Electrical Characteristics for Unbalanced Double-current Interchange Circuits

q. CCITT V.31, Electrical Characteristics for Single-current Interchange Circuits Controlled by Contact Closure

2. Communications Codes

a. ANSI X3.4-1968, American Standard Code for Information Interchange (ASCII) (Same as FIPS PUB 1, November 1, 1968, with one exception. That exception is not included in MIL-STD 188C which is to be replaced by MIL-STD 188-200)

b. ISO 646-1973, Seven-Bit Coded Character Set for Information Processing Interchange (international prototype for ASCII)

c. CCITT V.3-1972, International Alphabet No. 5 (similar to the International Reference Version in ISO 646)

d. Extended Binary Coded Decimal Interchange Code (EBCDIC), IBM Corporate Systems Standard, CSS 2-8015 (not otherwise recognized as a standard)

e. Encryption Algorithm for Computer Data Protection, as published in the <u>Federal Register</u>, Vol. 40, No. 52, March 17, 1975, pp. 12134-39 (proposed Federal Standard, identical to an IBM algorithm)

f. EIA RS-358, Subset of USA Standard Code for Information Interchange (ASCII) for Numerical Machine Control Perforated Tape, July 1968

g. ISO 840-1973, Numerical Control of Machines--7-Bit Coded Character Set

h. EIA RS-274C Interchangeable Perforated Tape Variable Block Format for Positioning, Contouring and Contouring/Positioning Numerically Controlled Machines, June 1974"

i. ANSI X3.32-1973 (FIPS PUB 36, June 1, 1975), Graphic Representation of the Control Characters of ASCII

3. Communication Protocol (Link Level) Standards

<u>Character Oriented</u>

a. ANSI X3.28-1972 ISO/ECMA - 1745, 2111 (competitive with IBM (BISYNCH))

<u>Bit Oriented</u>

a. ANSI Proposed Standard ADCCP - X3S34/589 (ANSI) Draft 4, ISO/ECMA - 3309, 4335, (similar to SDLC, (IBM), BDLC (Burroughs); (competitive with DDCMP (DEC))

4. Communication Protocol (Network Level) Standards

a. CCITT DRAFT X.25 proposed standard on Packet Switching (similar to ARPA, DNA (DEC), SNA (IBM), and Canadian Datapac SNAP)

B. <u>Computer System Standards - Languages</u>

1. General Purpose Programming Languages

a. Proposed ANSI Standard X3J2/76-01 BASIC

b. FIPS PUB 21-1/ANSI X3.23-1974 COBOL

c. ANSI X3.9-1966, X3.10 - 1966 FORTRAN

d. MDC/28, 33, 34-1976 MUMPS

e. ANSI BSR X3.53 BASIC/1-12-Feb. 1975 PL/1

2. Simulation Languages (not formal standards)
   a. CSMP
   b. DYNAMO
   c. GASP
   d. GPSS
   e. SIMSCRIPT
   f. SIMULA

3. Machine Oriented System Implementation Languages (not formal standards)
   a. BLISS-10 (PDP-10)
   b. BLISS-11 (PDP-11)
   c. PL/S (IBM-360/370)
   d. PL/360 (IBM-360/370)
   e. C (PDP-11/UNIX)
   f. BCPL (TXZ, TENEX, PDP-11)
   g. PL/M (INTEL 8080)
   h. PL/M6800 (MOTOROLA M6800)

4. Artificial Intelligence Languages (not formal standards)
   a. LISP
   b. SAIL

C. <u>Computer System Standards - Data Base Management Systems</u> (not formal standards)

   1. CODASYL Data Base Task Group Specification
   2. Non-CODASYL Self-Contained Approach
   3. Non-CODASYL Host Language Approach
   4. Relational Approach

D. <u>Computer System Practices - Operating Systems</u> (not formal standards)

   1. Job Control
   2. Storage Management
   3. File Systems

E. Computer System Standards - Validation and Testing

1. Fed. Prop Management Regulations 101-32.1305a. Validation of COBOL Computers

2. NBS Special Publication 399, Vol. 1-3 "NBS FORTRAN Test Programs" Available through N.T.I.S. number COM-75-10182/4WC

F. Computer System Standards - Documentation

1. Documentation Standards

   a. FIPS PUB 30 Software Summary for Describing Computer Programs and Automated Data Systems

   b. FIPS PUB 38 Guidelines for Documentation of Computer Programs and Automated Data Systems

   c. FIPS PUB 24 Flow Chart Symbols

   d. Group of FIPS Data Element Stds, to include date, location codes, etc.

G. Computer System Standards - Media

1. IBM Cards

2. Magnetic Tape

3. Paper Tape

Figure 1

U.S. Army Rock Island Arsenal Pilot Automated Shop Loading & Control System (PASLACS)

The Rock Island Arsenal PASLACS specifications show the function of early CAM systems for scheduling and control, many of which are still in active use.

Each of the functions shown is typically a batch program with data input prepared for each specific run.

This schematic is particularly useful in showing the feedback required in a scheduling and control system for batch manufacturing.

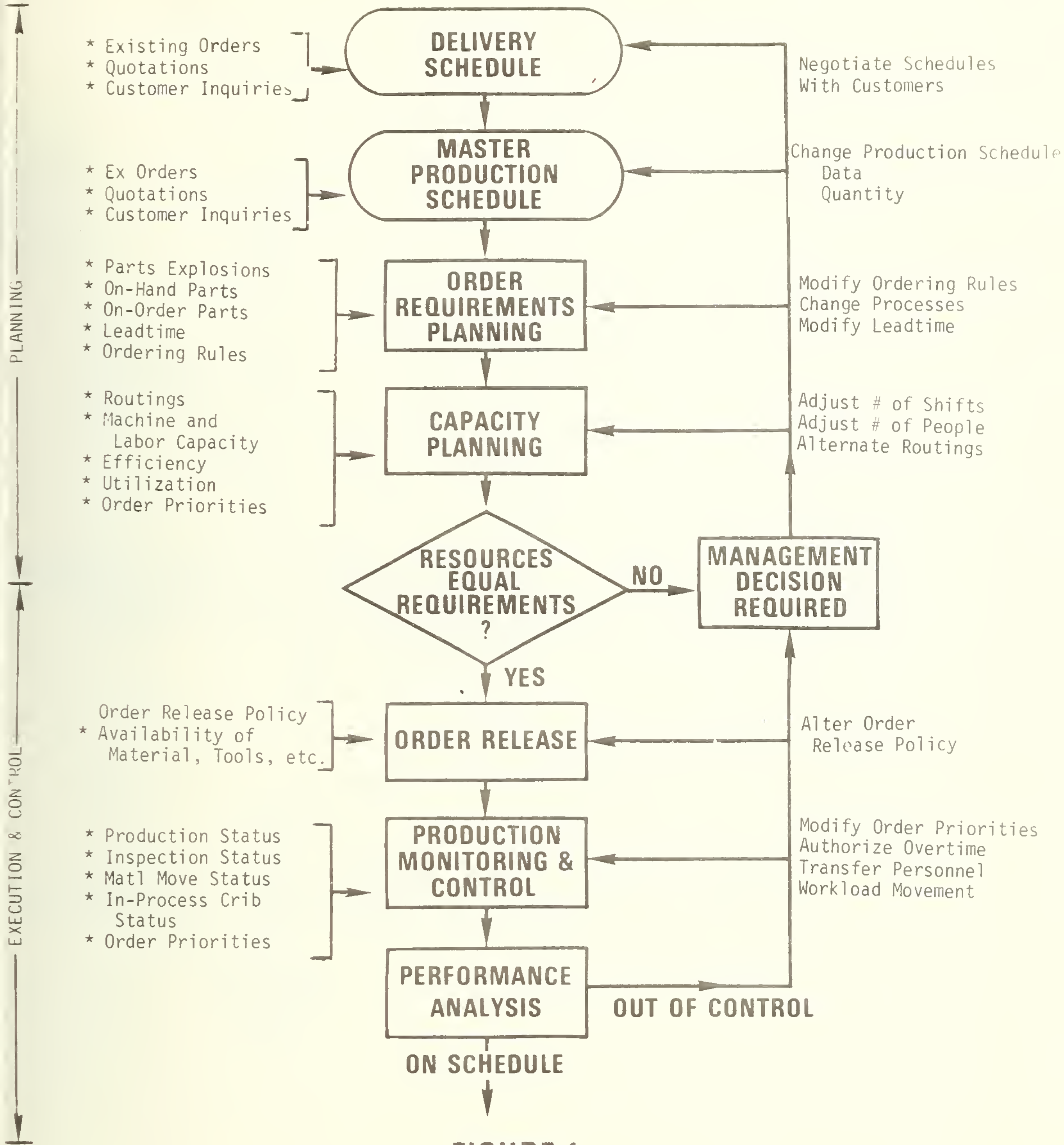


FIGURE 1

U.S. ARMY ROCK ISLAND ARSENAL PILOT AUTOMATED SHOP LOADING & CONTROL SYSTEM (PASLACS)

Figure 2

AUTOKON 71

The AUTOKON 71 system is a set of batch computer programs for ship design and fabrication linked directly or indirectly to a central data base manager. The system was developed in Norway and purchased by the Maritime Administration (MARAD) of the U.S. Department of Commerce for use by U.S. shipbuilders. The Illinois Institute of Technology Research Institute maintains this software under contract to MARAD.

The programs are:

FAIR, DRAW, TRABO: Fairing programs
ALKON: NC flame cutter part programming
NEST, PRODA: Assist in developing flame cutting programs
LANSKI: Longitudinal curves
SHELL, TEMPLATE: Hull plate programs
DUP: File management utility.

AUTOKON is a computer aided design and NC part programming system. PASLACS, Figure 1, covers only scheduling and control. Both concepts are part of computer aided manufacturing.

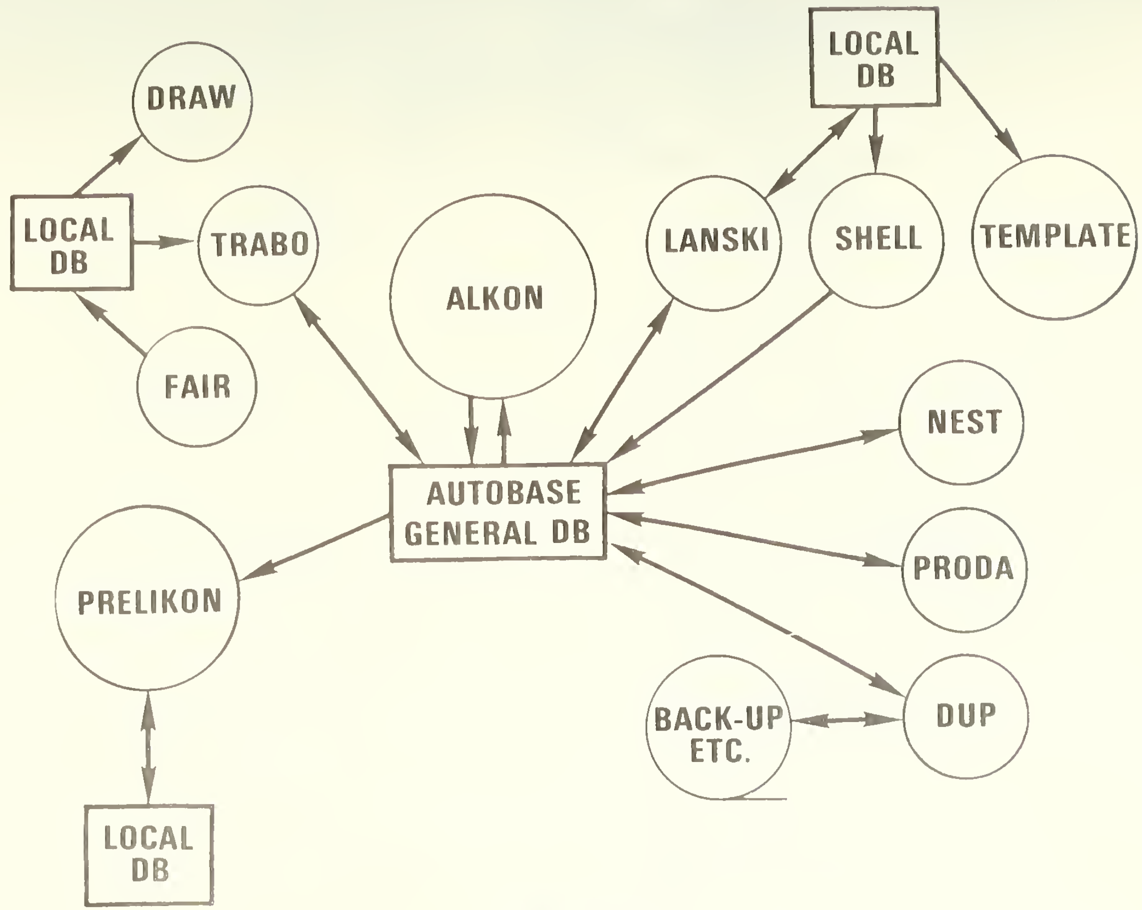


FIGURE 2
NORWEGIAN AUTOKON 71 SYSTEM
FOR SHIP DESIGN AND FABRICATION

Figure 3

COPICS Concept

The IBM Communications Oriented Production Information & Control System (COPICS) concept emphasizes the idea of CAM systems created around a central data base with a data base management system (DBMS). COPICS is a conceptual design study not a specific product. The system is conceived of being implemented on one computer or several linked computers, with possibly hundreds of terminals accessing the system throughout a company on a real time interactive basis. The system thus depends on modern multi-user, real time operating systems with DBMS capability.

FIGURE 3
IBM COPICS (COMMUNICATIONS ORIENTED PRODUCTION INFORMATION & CONTROL SYSTEM) CONCEPT

Figure 4

McDonnell Douglas CAM Concept

All of the production and service departments shown on the opposite page can (or will in the future) access the data and programs of the MCAIR CAM system which runs on the computers of McDonnell Douglas Automation Company. This system is essentially an implementation of the COPICS concept of Figure 3.

The diagram shows the extent of applications coverage of a major state of the art CAM system.

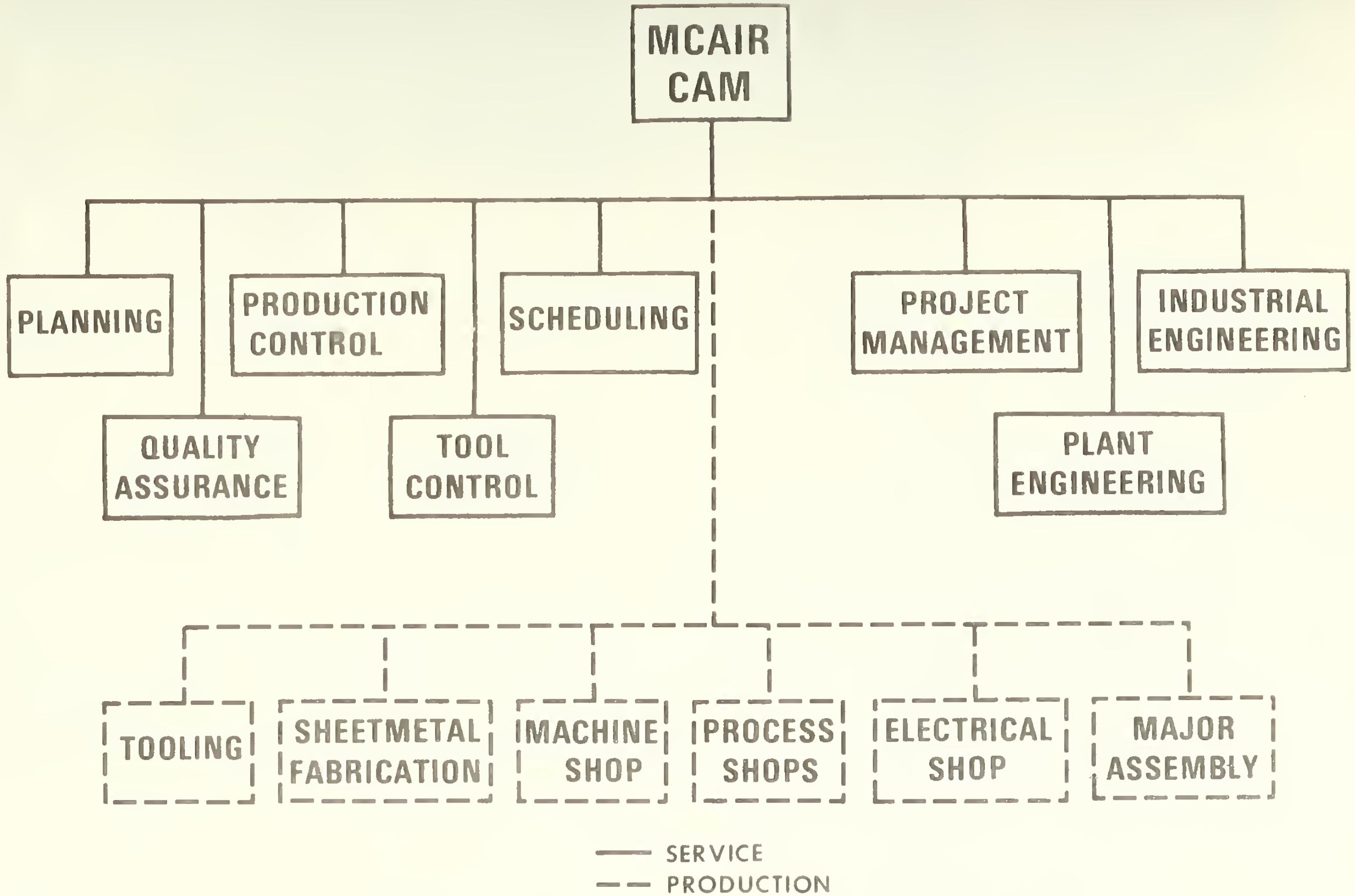


FIGURE 4
McDONNELL AIRCRAFT CAM DEPARTMENT

Figure 5

Caterpillar CAM System

This diagram shows the use of integrated CAM concepts outside the aerospace industry. The Caterpillar system, which could be applied to any large batch manufacturing operation, shows the integration of design, process planning, and manufacturing operations in a single system with a central data base structure.

The basic information flow in this integrated system, from left to right with feedback loops, is clearly shown.

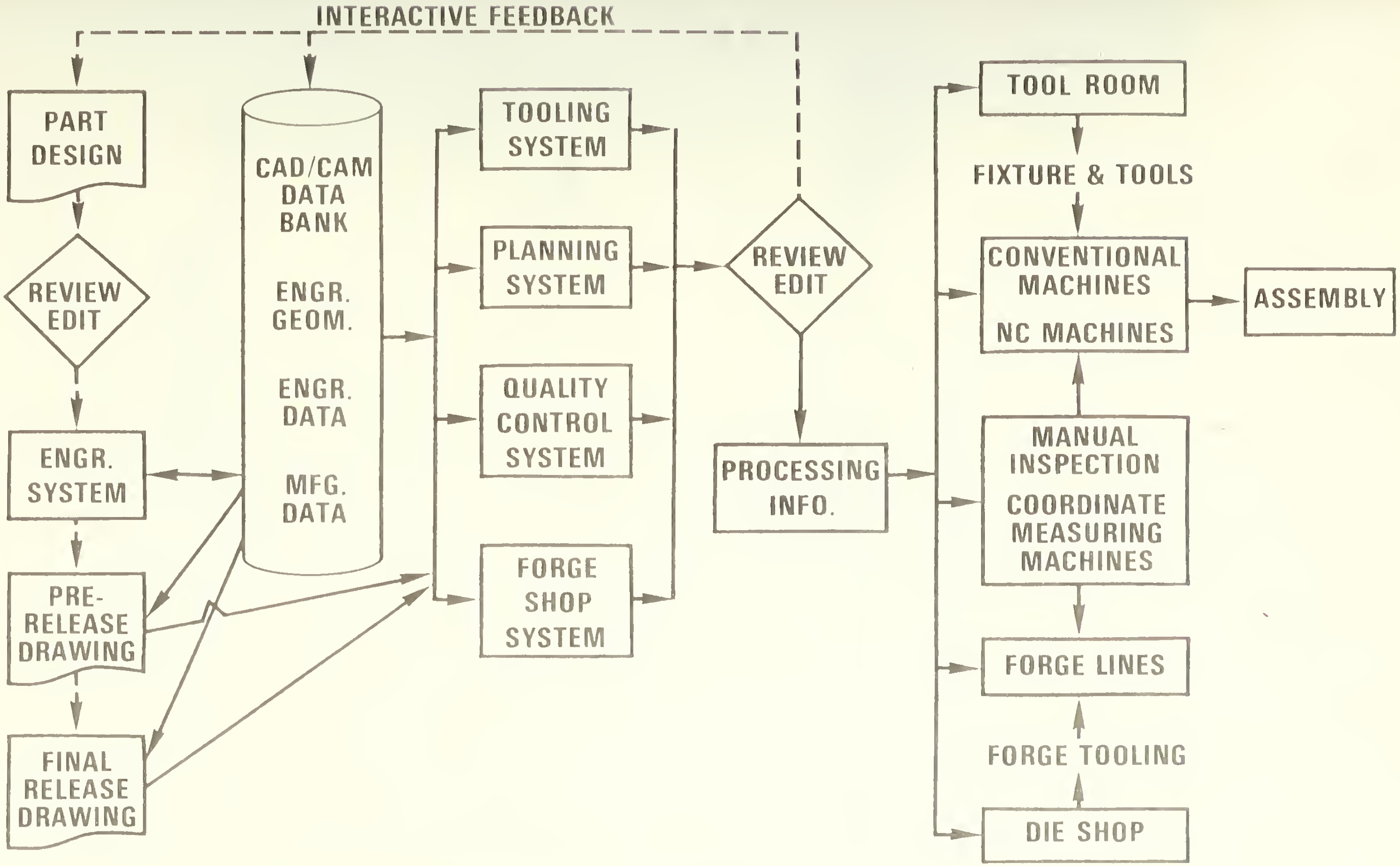


FIGURE 5
CATERPILLAR TRACTOR COMPANY CAD/CAM CONCEPT DIAGRAM

Figure 6

Air Force ICAM Architecture

The Air Force ICAM (Integrated Computer Aided Manufacturing) concept is similar to the COPICS concept, Figure 3, but adds a third layer of software: general purpose utility programs, including simulation capability to create a "smart" data base system.

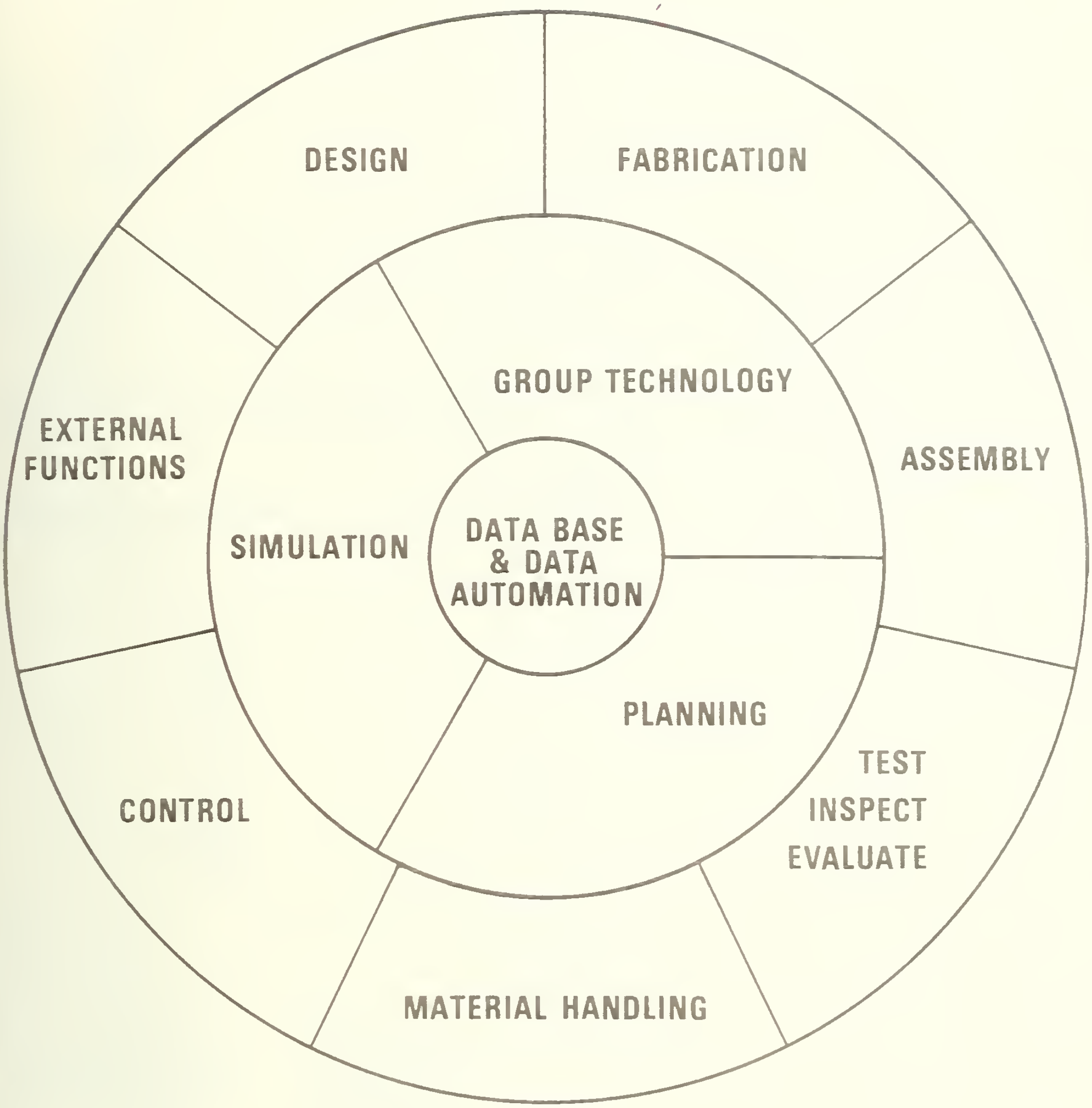


FIGURE 6
AIR FORCE ICAM (INTEGRATED COMPUTER AIDED MANUFACTURING) ARCHITECTURE

Figure 7

CAM-I Cell Model

Computer Aided Manufacturing-International, Inc. (CAM-I) is a not-for-profit organization of industry, Government, and universities dedicated to advancing the use of computers in manufacturing.

The Advanced Technical Planning Committee of CAM-I has created a cell model diagram of manufacturing. This diagram shows 6 basic functions of manufacturing. The nomenclature used in earlier figures would be: design, planning and scheduling, process planning, inventory control, manufacturing control, and shipping.

This diagram is one structuring of the functions needed in an integrated CAM system and should be compared with Figure 5, which has a comparable but different partitioning.

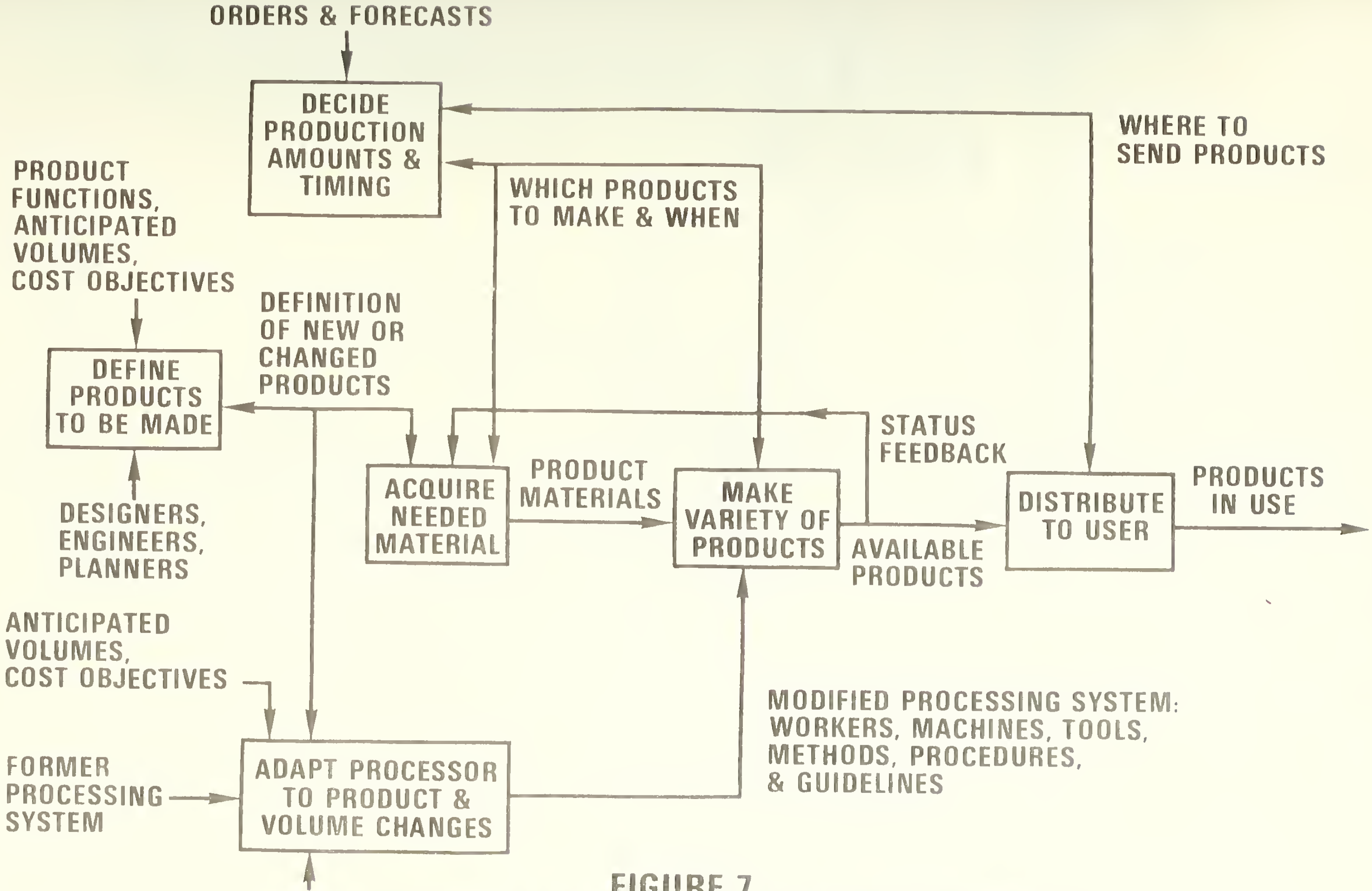


FIGURE 7
CAM-I ADVANCED TECHNICAL PLANNING COMMITTEE
CELL MODEL DIAGRAM OF MANUFACTURING

Figure 8

CAM-I Standards Committee CAM Architecture

A CAM system may be strictly defined as a set of computer programs which process data. Working from the cell model diagram in Figure 7, the CAM-I Standards Committee created this diagram of a CAM system.

The functions and data flows of this diagram should be compared with Figures 1 and 5.

The data bases, shown as circles in the diagram, are:

1. Production Schedule
2. Product Design
3. Raw Material Inventory
4. Work-In-Process, Finished Goods Inventory, Machine Tool Utilization
5. Shipments
6. Overall Manufacturing Plan (Routing Sheets, Tooling, Part Programs, QC Plans)
7. Production Order Release, Production Plans and Schedule
8. Schedule, Process or Product Revision Requirements
9. Group Technology Data Base (Parts Data, Standard Plans)
10. Management Data: Output Node
11. External Information: Input Node (Marketing Information, Customer Orders, Product Functions, Cost Objectives, Anticipated Production Volumes)

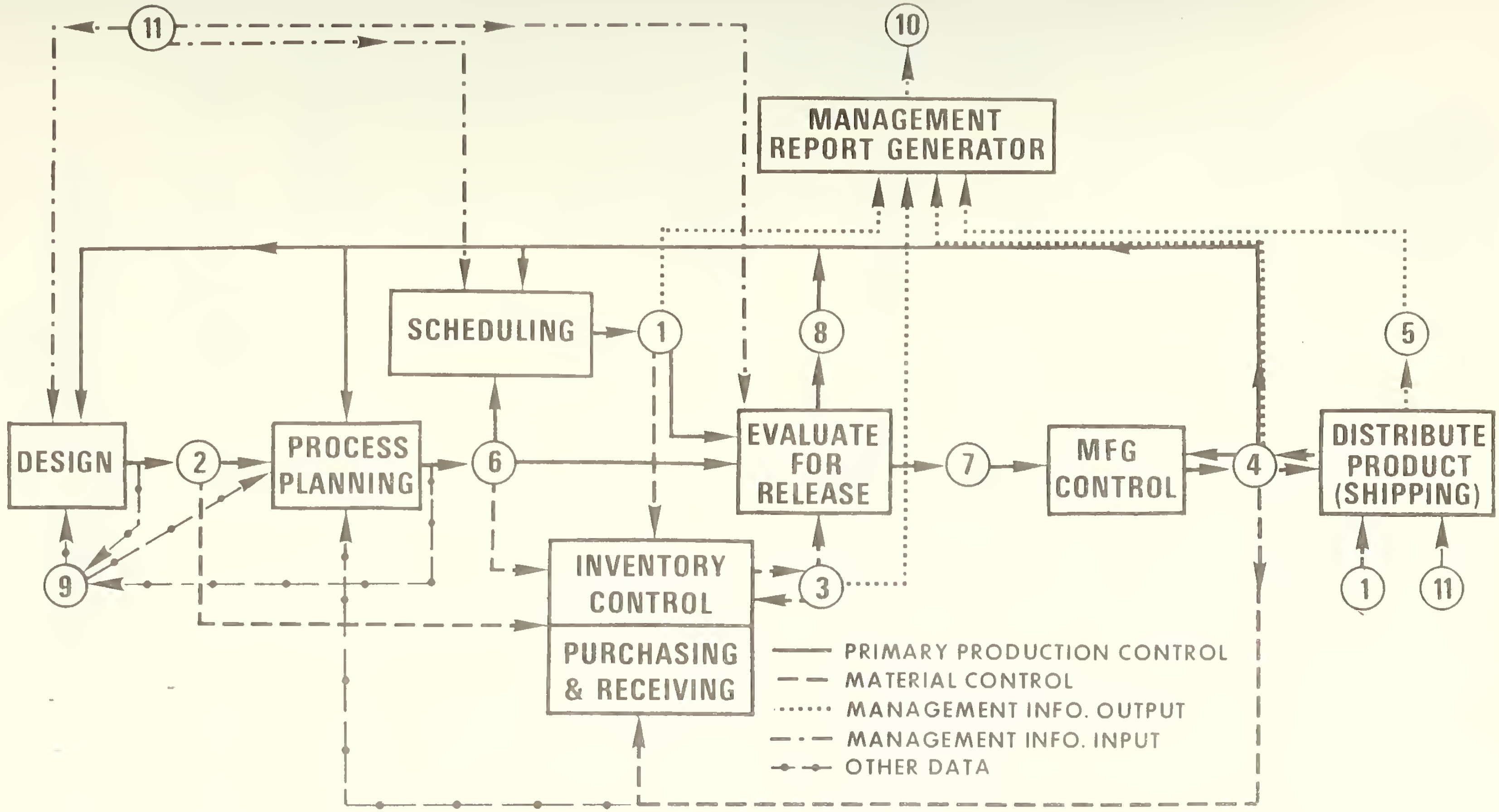


FIGURE 8
CAM-I STANDARDS COMMITTEE CAM ARCHITECTURE

Figure 9

Architecture of a Computer System

Two computers out of a distributed network are shown in this figure. This diagram shows the interfaces between the application programs and the host system and between various computers and provides a visual framework for discussing standards important to software integration and portability in a distributed system.

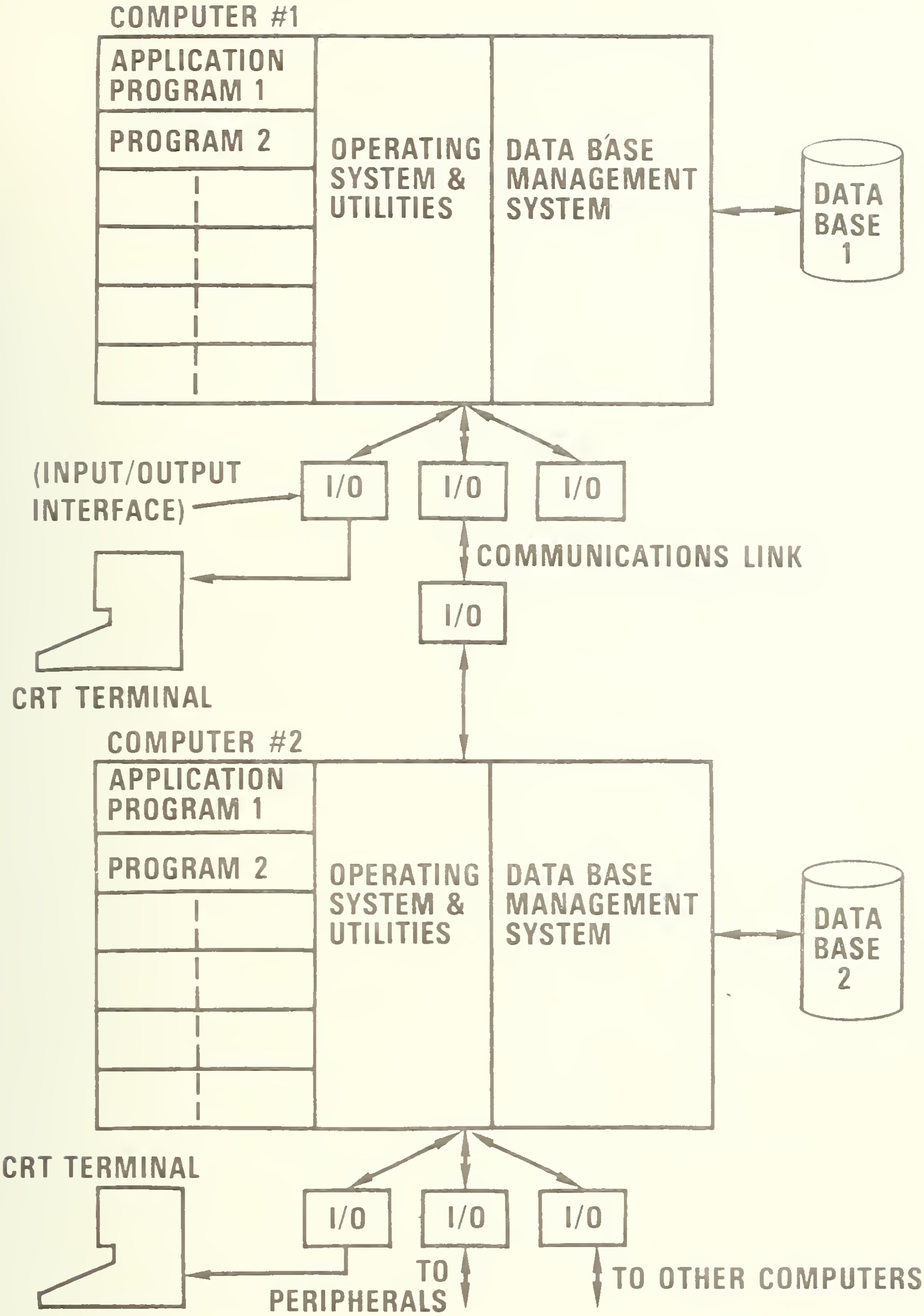


FIGURE 9
ARCHITECTURE OF A COMPUTER SYSTEM USED IN A CAM SYSTEM

APPENDIX A

11 February 1976

STATEMENT OF WORK

"National Bureau of Standards Support in the Determination and Evaluation of U.S. Industry Standards Applicable to the Development of a Computer Aided Manufacturing Architecture"

1.0 OBJECTIVE

The objective of this effort is to provide the Air Force with definition and analysis of existing and potential standards which are necessary for the optimum development and implementation of integrated computer aided manufacturing. The Air Force Computer Aided Manufacturing Program team will develop a close working relationship with the National Bureau of Standards staff. This relationship will serve as a basis for continued co-involvement in the standards area throughout the Computer Aided Manufacturing Program. Results from this effort will provide the Air Force with a sound basis upon which to structure the development of individual computer based subsystems so that these systems not only work independently, but are able to perform as an integrated computer aided manufacturing system.

2.0 SCOPE

Five tasks are outlined to fulfill the objectives of this program.

2.1 Identify and provide current standards applicable to computer aided manufacturing.

2.2 Analyze current standards.

2.3 Assess actual usage of standards throughout industry.

2.4 Hypothesize optimal standards for integrated computer aided manufacturing.

2.5 Assess the relative roles of existing standards organizations and the Air Force in organizing for the development of optimal standards for computer aided manufacturing.

The existing expertise and experience level of the NBS with respect to standards, standards usage, standards conflicts and standards organizations will be called upon to perform the program tasks. Especially in task 2.3, but in general for all tasks, additional information information should be gained from outside government and industry sources to the extent required to increase the confidence level in task results. Hypotheses about future standards needs should also deal mostly with NBS experience and should be tested by outside sources only to the degree required to insure confidence in results.

The results of each task will be a report containing findings, conclusions and recommendations as appropriate according to Section 5. In addition, monthly written reports will be provided to AFML/LT identifying both progress and problems. A close verbal working relationship is also expected between NBS and the Air Force Computer Aided Manufacturing team during program execution.

3.0 BACKGROUND

Developments in the use of the computer as an aid to manufacturing have proceeded in a modular but disjointed fashion. Hardware and software systems have been designed and developed to solve the particular problem of the day and have been by and large limited in scope in order to most expediently aid the performance of a particular manufacturing function. The events subsequent to the development of N/C machine tools and the APT language are examples of this approach. Integration of these systems has been attempted in some cases, but only as an afterthought. This situation has resulted in the proliferation of disjointed computer software and hardware that has in many ways tended to actually magnify problems in manufacturing.

The long term adverse effect of continuing development in this way has been recognized both in the United States and in many foreign countries. Information compiled by the Comptroller General of the United States and others suggests that foreign nations have not only identified this problem, but have developed national programs aimed directly at providing strong impetus to increased productivity through the application of integrated Computer Aided Manufacturing systems.

The evidence, both abroad and in this country, advises that the economic and sociological benefits to be gained from this integration far exceed those benefits that have been accepted as being directly attributable to individual development efforts. This is particularly true in discrete parts-batch manufacturing based-industries because of such factors as the dual requirement to maintain both a flexible fabrication base and a highly efficient, controlled operation. These companies comprise a high percentage of U. S. industry, but their individual outputs are relatively small. The prime aerospace companies and their vast network of subcontractors fall into this group.

The Air Force recognized these facts and in 1973 produced a conceptual master plan (AFML-TR-74-104) which attempted to identify and group the major functions of manufacturing so that an organized approach at integration could evolve. The results of this contractual effort were briefed to American industry in June of 1974. At that time there appeared to be a general opinion in industry that an important new data base in support of integrated Computer Aided Manufacturing had been created, but there was little agreement in either the public or the private sector as to a subsequent course of action. Dialog in this vein continued between industry and DoD for the remainder of 1974. Subsequently, further study of Computer Aided Manufacturing was undertaken in 1975 by the Air Force in response to a memorandum by Deputy Secretary of Defense, W. P. Clements. This study focused on the state of the production art in aerospace and related industries. Its primary objective was identification of cost saving opportunities in the production of defense materiel through the application of computers and elements of computer technology. Among the conclusions was that subsystem integration provides the key to ultimate benefit realization in this area.

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NASA, through the IPAD Program, is attempting to accomplish the same objective in the design area, but through the use of a single, dedicated hardware/software computer system. Other organizations such as the Aerospace Industry Association, Computer Aided Manufacturing-International Incorporated, the Society of Manufacturing Engineers, the National Science Foundation (RANN Program) and possibly others have also attempted to evolve programs which consider not only advances in individual areas of manufacturing, but also the relationship of some of these areas.

All of these programs recognize the need for an organized plan for integration of subsystems in order to insure such factors as portability of software and adequacy of communications. However, to date, although it is clear that a key to affordable integration is through the use of various types of standards, no effort has been made to specifically identify and characterize actual requirements which would enable integration of Computer Aided Manufacturing subsystems.

In addition, while good work continues to be accomplished in areas related to Computer Aided Manufacturing by various standard groups, such as ANSI, ISO, EIA, NCS, SME, IEEE, CAM-I and some computer system manufacturers, no work has been done to identify potential conflicts or to establish a master plan for standards development.

The Air Force has proposed a major new initiative in the development of Computer Aided Manufacturing. This is a long term program which includes development of individual subsystems within the general areas displayed in Section 5, Attachment 2. The long term goal of this program is totally integratable Computer Aided Manufacturing.

In its ultimate, this would allow manufacturing activities to be performed in a manner which today is only barely within the ability to comprehend -- both managerially and technically. For example, two illustrative, conceptual goals could be:

(1) The ability for a part designer to not only optimally design a part, but at the same time to subject this part to a performance evaluation and to plan for the most economical fabrication of the part within the constraints of schedule and availability of raw materials. Further, it could be envisioned that the fabrication test may be performed immediately and the part production may be automatically introduced into the overall manufacturing plan.

(2) A manufacturing capability where all information is available in standard data formats "on time" via computer display and where the chief executive's staff could be able to perform "what if" simulation ranging from global risk analysis to plant layout.

The first five years of this program have been outlined in some detail. Included are projects that are both quite specific within the functional areas of manufacturing and projects solely designed to effect the interface of code within subsystems and communications between subsystems. Some of these projects will advance the state of the art in discrete areas such as sheet metal part fabrication and assembly. These projects are required both for the long-range goal and in order to demonstrate short-term payoff. But, even in short-term projects, the overriding goal is integration. This can only be accomplished through the use of interface standards, acceptable validation procedures and techniques and other such concepts.

It is definitely not the intent of the Air Force to legislate in these areas, neither does it seem feasible that all standards related problems can be solved with today's technology. This is also a most dynamic environment and the probability and possibility of change must be allowed in order to accommodate unforeseen technical advances and to not stiffle individual initiatives. Nevertheless, it is believed that both problems and requirements must be at least recognized in the early stages of the Computer Aided Manufacturing Program. Where existing standards will aid integration, they should be utilized. Where standards do not exist, they should be developed by the appropriate agency and then adopted within the Air Force Program. Where conflicts arise, they should be identified and a plan for their resolution outlined.

4.0 TASKS/TECHNICAL REQUIREMENTS

4.1 The first task involves the accumulation and grouping of current standards which may be relevant to the use of computers in all aspects of manufacturing.

4.1.1 For the first report NBS shall obtain and provide the Air Force with copies of all current standards which may be relevant to the use of computers in all aspects of manufacturing. As a minimum, such areas as CAD/CAM interfaces, hardware interfaces, software interfaces and procedures, communications codes and protocols, test validation concepts, security issues, Federal Information Processing Standards (FIPS), et al, which apply to manufacturing shall be addressed.

4.1.2 NBS shall organize these published standards into logical groupings for easy reference by the reader. A graphical matrix display of these groupings shall be prepared as part of the Task Report.

4.1.3 NBS shall develop a bibliography of all standards obtained for Task 4.1.1 and include this in the first report as identified in Section 5, Attachment 1.

4.2 NBS shall analyze standards obtained in Task 4.1.1 in order to determine the merit of various standards or groups of standards for use in integrated Computer Aided Manufacturing.

4.2.1 NBS shall analyze each standard or groups of standards (as appropriate) obtained in Task 4.1.1 for the standards merit in terms of relevance for use in integrated Computer Aided Manufacturing. NBS shall identify existing and potential conflicts between standards or groups of standards considering such factors as: fitness for use in particular application approaches and stability in light of advancing manufacturing and computer technology.

4.2.2 NBS shall modify the matrix of Task 4.1.2 in order to clearly display the results of Task 4.2.1 in graphical form.

4.2.3 Task 2.0 report of NBS shall annotate the bibliography obtained in Task 4.1.3 and shall include this bibliography and the matrix of Task 4.2.2 as part of the Task Report identified in Section 5, Attachment 1.

4.3 Standards actually in use today within manufacturing industries should be identified. This shall include both those standards displayed in Task 4.1 and any additional private standards which may be of significance to the CAM Program. Included shall be both computer based standards now in use as well as those standards likely to be affected or which must be considered in the application of computers to aid a particular manufacturing function.

4.3.1 Standards actually in use should be identified including communications codes, protocols and line disciplines. Of particular interest are defacto communications and security standards which may be evolving as a result of advanced network research and recent announcements by IBM, Digital Equipment Corporation, and Control Data Corporation.

4.3.2 NBS shall develop a report at the completion of this task summarizing the actual usage of standards as identified in Section 5, Attachment 1.

4.4 Upon completion of the analysis of current standards in Task 4.2 and the assessment of the usage of standards in Task 4.3, hypotheses from NBS about the most appropriate ("best") standards for specific applications are required.

4.4.1 NBS shall integrate their experience and expertise with their findings from Task 4.2 and Task 4.3 and for each standard or set of standards identified in Task 4.1.2, NBS shall recommend the "best" to be used in integrated Computer Aided Manufacturing.

4.4.2 If new standards are suggested, status and timing for development of these new standards should be outlined and suggested mechanisms for development of these needed new standards explained.

4.4.3 If existing standards require modification, then status and timing for changes shall be outlined and mechanisms explained as per Task 4.4.2.

4.4.4 When existing standards meet the "best" requirements, these should be noted.

4.4.5 NBS shall clearly display the results of Task 4.4 through modification of the matrix of Task 4.2.

4.4.6 All requirements of Task 4.4 shall be included in the fourth Task Report as identified in Section 5, Attachment 1.

4.5 A review of existing standards orgdnizations shall be performed in order to identify issues such as potential conflicts, duplication of effort and procedural approaches which should be addressed in conducting the integrated Computer Aided Manufacturing Program.

4.5.1 The present and planned activity of existing standards organizations such as ANSI, ISO, IEC, EIA, NCS, SME, CAM-I shall be assessed to identify potential conflicts and duplication of effort which should be addressed by the Air Force in resolving issues or filling in holes displayed in the matrix of 4.4.5.

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4.5.2 These organizations shall be reviewed to identify the most effective individual structures and procedural approaches which are utilized.

4.5.3 An approach including funding, time phasing and required working relationships shall be outlined to result in the most effective standards and their related practices and procedures for integrated CAM.

4.5.4 All requirements of Task 4.5 shall be included in the fifth task report identified in Section 5 of Attachment 1.

5.0 DELIVERABLE REPORTS

5.1 This Statement of Work contains five (5) tasks to be performed by NBS. Each task has a report as its end product. These reports are deliverable items due thirty (30) days after completion of each task.

5.2 The task schedules, program reviews and report delivery dates are identified by the contract Milestone Chart (Attachment No. 1 of this Section).

6.0 SPECIAL CONSIDERATIONS

6.1 All AFML funded travel by NBS personnel necessary for this program shall be subject to AFML Project Manager approval.

NBS-114A (REV. 7-73)

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15. SUPPLEMENTARY NOTES

16. ABSTRACT *(A 200-word or less factual summary of most significant information. If document includes a significant bibliography or literature survey, mention it here.)*

This report identifies and evaluates those existing and potential standards which will be useful to the Air Force in the development and implementation of integrated computer aided manufacturing (ICAM) systems. Such systems, when implemented by the Air Force and by Air Force contractors, will increase productivity in discrete part batch manufacturing by several thousand percent. The use and importance of standards are considered in the context of CAM systems. Since the Air Force will develop the detailed ICAM architecture after this study is complete, existing system concepts and architectures are examined to identify the common elements to guide the further presentation and discussion of relevant standards.

17. KEY WORDS *(six to twelve entries; alphabetical order; capitalize only the first letter of the first key word unless a proper name; separated by semicolons)*

CAM architectures; computer aided manufacturing; computer systems; standards; system integration; voluntary standards.

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